

Effect of Tabs on a Rectangular Nozzle Studied

In a continuing research program, jets from nozzles of different geometries are being investigated with the aim of increasing mixing and spreading in those flows. Flow fields from nozzles with elliptic, rectangular, and other more complex cross-sectional shapes are being studied in comparison to circular nozzles over a wide Mach number range. As noted by previous researchers, noncircular jets usually spread faster than circular jets.

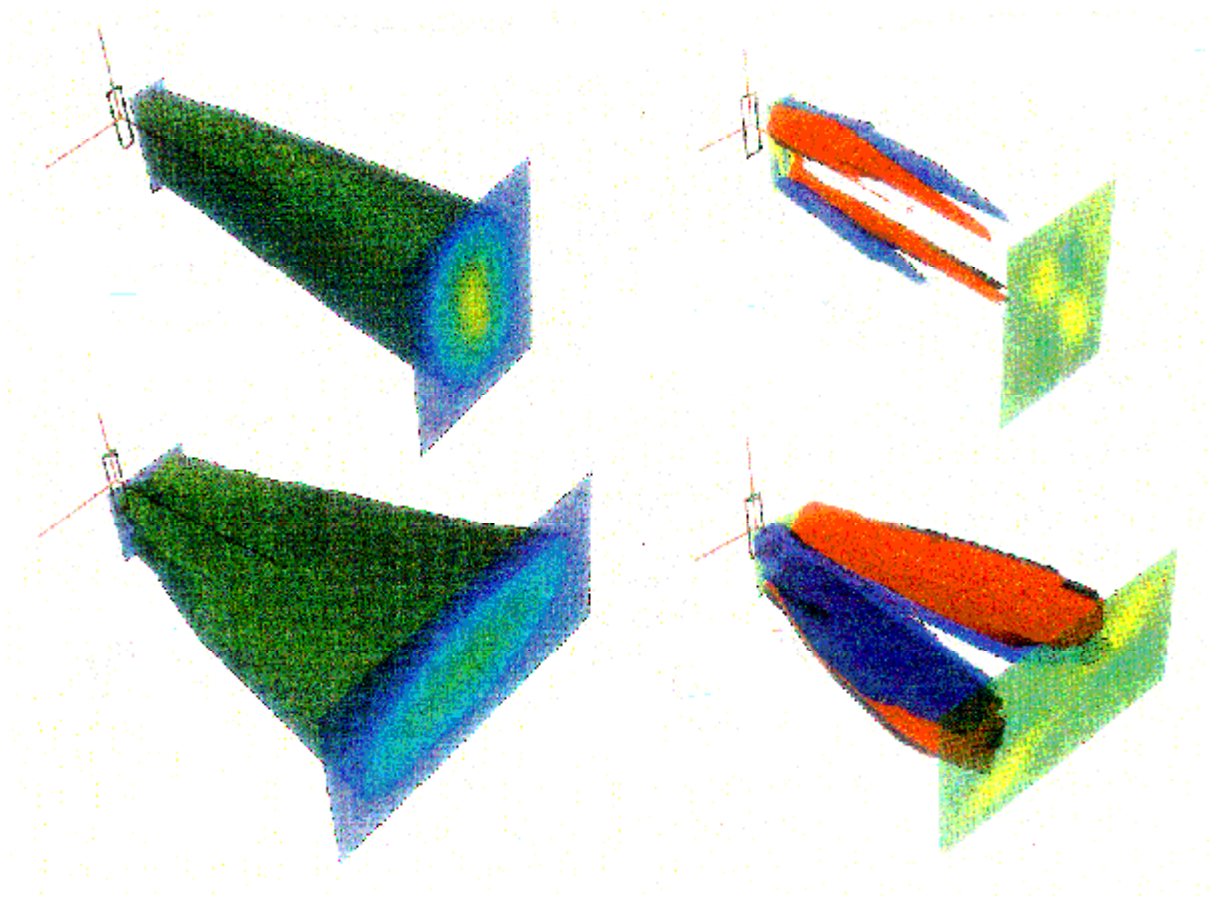
Another technique being investigated to increase jet spreading even further for a given nozzle is the use of "tabs" to generate vortices. A typical tab is a triangular-shaped protrusion placed at the nozzle exit, with the base of the triangle touching the nozzle wall and the apex leaning downstream at 45° to the stream direction. This geometry was determined by a parametric study to produce the optimum effect for a given area blockage. The tabs can increase jet spreading significantly. The underlying mechanism traces to a pair of counter-rotating streamwise vortices originating from each tab. These vortex pairs persist in the flow; and with the appropriate number and strength, they can increase spreading.

With jets from noncircular nozzles, the effect of the tabs is relatively more complex. Such flows usually contain streamwise vortices, even without any tabs, because of the tortuous flow paths within the nozzle. When tabs are applied, the resulting vortex pairs interact with the already existing vortices. Thus, depending on the location, size, and orientation of the tabs, the vortex interaction can be either beneficial, increasing spreading, or detrimental, actually reducing spreading.

With a suitable choice of the tabs, a large increase in jet spreading can be achieved with noncircular nozzles. An example is shown in the figure. Here, the nozzle is rectangular with an aspect ratio of 3:1. The Reynolds number is 450,000, and the Mach number is 0.3. The data are obtained by hot-wire anemometry. Each figure in the left column shows an "isosurface" of the mean velocity, $U/U_{JET} = 15$ percent, providing a perspective view of the jet spreading. It can be seen that the jet cross section for the no-tab case has become essentially round by the last measurement station, $x/D_{EQUIVALENT} = 8$. For the case in the lower figure, two relatively large tabs are used, one each on the narrow edges of the nozzle. The tabs cause an enormous increase in the jet spreading. The increase in the amount of entrained ambient air at $x/D_{EQUIVALENT} = 8$ is about 100 percent. Note also that the tabs cause "axis switching"; that is, whereas the long dimension of the nozzle is aligned vertically, that of the jet cross section becomes horizontal shortly downstream of the nozzle.

The two figures on the right show the corresponding distributions of streamwise vorticity. Looking from downstream, the red and blue isosurfaces represent regions of anticlockwise and clockwise rotation, respectively. In the no-tab case, as mentioned earlier, two pairs of vortices occur because of secondary flow within the nozzle. It should be evident that the tabs produce very strong vortex pairs with opposite rotation directions. These vortex pairs

completely dominate the flow field, and are responsible for the observed increase in the jet spreading as well as the axis switching. The effect of the tabs in this configuration has also been found to be persistent and, in fact, more pronounced at supersonic conditions.



Distributions of mean velocity and streamwise vorticity with and without the tabs. Nozzle exit is shown on the left of each figure; flow is from left to right.

Current effort in the research includes testing with more practical nozzles relevant to the High Speed Civil Transport (HSCT) and the Advanced Subsonic Technology (AST) programs. Efforts are also under way to address fundamental issues: for example, vorticity dynamics, mixedness, and small-scale mixing, as affected by the tabs, relevant to combustor flows and jet noise. In a parallel computational study, the flow field was also simulated successfully by a three-dimensional Navier-Stokes analysis. Currently, a parametric study is being carried out in the computational work by varying the tab size, orientation, and other factors--complementing and guiding the experimental work.

Bibliography

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